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Automated Anthropometric Measuring Devices for Use in Mass-Screening

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13. ABSTRACT ***(Maximum 200 Words)***

The purpose of this report was to determine the state of the art in anthropometric measuring devices used for mass screening. In addition, technologies which could be used for mass screening were identified and described. Finally, straw-man requirements for an anthropometric measuring system were proposed.

A review of the literature identified only two operational anthropometric measurement devices currently used for mass screening. One was developed for the US Navy by Provost, Gifford and Lazo (1965). The other, Anthropometric Measurement System (AMS) was developed by Ergotech, a firm in Pretoria, South Africa, to "facilitate the efficient issuing of clothing items to defence force personnel." A prototype of an improved system, Automated Anthropometric Data Measurement System (AADMS) was developed by Moroney, Hughes & Spicuzza (1984), but was never used operationally.

A variety of potentially applicable measurement techniques were identified and described. Acoustic, light, electro-magnetic, and digitizing arm technologies could be used to measure individuals. Data describing the capabilities and limitations of these systems are also provided.

Finally a series of requirements to be included in a straw-man requirements document was provided.

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Abstract

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A review of the literature identified only two operational anthropometric measurement devices currently used for mass screening. One was developed for the US Navy by Provost, Gifford and Lazo (1965). The other, Anthropometric Measurement System (AMS) was developed by Ergotech, a firm in Pretoria, South Africa, to "facilitate the efficient issuing of clothing items to defence force personnel." A prototype of an improved system, Automated Anthropometric Data Measurement System (AADMS) was developed by Moroney, Hughes & Spicuzza (1984), but was never used operationally.

A variety of potentially applicable measurement techniques were identified and described. Acoustic, light, electro-magnetic, and digitizing arm technologies could be used to measure individuals. Data describing the capabilities and limitations of these systems are also provided.

Finally a series of requirements to be included in a straw-man requirements document was provided.

It was concluded that:

1) Any new system would require at least two stations, one standing and one seated.
2) Position sensors are needed to determine that the individual is positioned properly.
3) Accuracy of +/- 0.1 inches was adequate.
4) Any of the digitizing systems would provide the required accuracy, but tradeoffs would need to be made to ensure that the probes were positioned reliably and did not significantly increase the operator's workload. The author favors the use of potentiometric or optical encoding devices such as those incorporated into the AMS or AADMS.

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Objectives of this Report

The objectives of this report were to:

1) Identify anthropometric measuring devices currently in use for mass screening purposes. These devices should be able to measure some or all of the anthropometric measurements used to assign naval aviators to aircraft.
2) Identify technologies which could be used in a mass screening device.
3) Describe the advantages and disadvantages of the measuring devices identified and the technologies available.
4) Prepare a straw-man requirements statement for the development of an automated anthropometric measuring device.

Approach

The overall approach included:

1) Part I: Identifying anthropometric measures of interest.
2) Part II: Collecting literature and identifying individuals knowledgeable in the field of anthropometrics. This search focused on devices used for mass screening.
3) Part III: Reviewing and analyzing relevant literature.
4) Part IV: Preparing the report and developing the straw-man requirements.

Each of these parts is discussed independently in the following sections.

Part I: Identification of Anthropometric Measures of Interest

The anthropometric measures of interest were discussed by the attendees of the November 14, 1994 meeting at Naval Aerospace Medical Research Laboratory. Mr David Rose of the Naval Air Warfare Center, Aircraft Division, Code 6022, determined the final list of measures of interest. The specific measurements and their definitions are presented in Table 1. The data acquired by the measurement system are intended for incorporation into the Anthropometric Cockpit Assignment Program developed by CHI Systems. A broad overview of the efforts in the area of aircrew accommodation assessment is provided by Price (1993).

Part II: Collecting Literature and Contacting Knowledgeable Individuals

This multi-pronged effort involved these steps:

1) Literature searches of the following databases were performed: DTIC-DROLS, NTIS, NASA-RECON, COMPENDEX. Related patents were also examined.
2) Individual contacts with government agencies engaged in measuring personnel for cockpit/workstation assignment/restriction were initiated.
3) Individual contacts with commercial activities engaged in measuring personnel for cockpit assignment/restriction were initiated. Activities contacted included: Grumman, MCAIR, and Anthropology Research Project Inc.
4) Requests for information were distributed to professional groups (e.g., the announcement in Appendix A was distributed at the 1994 & 1995 annual meetings of the Brouha Society and at the 1995 meeting of the Human Factors and Ergonomics Society. Finally, a request for information was distributed to the approximately 3000 members of the Biomechanical Discussion Forum sponsored by the International Society of Biomechanics.
5) Individual contact was made with commercial activities engaged in manufacturing mensuration devices compatible with the needs of the screening program. The World Wide Web was searched as part of this process.

Part III: Review and Analysis of the Relevant Literature

Material which appeared to be relevant was gathered by CSERIAC, or obtained through Inter-Library Loan or personal request. When appropriate, knowledgeable individuals identified through this search strategy were contacted for further information. The author did not include studies which developed unique measures for evaluating an individual's compatibility with specific cockpits, thus studies such as the work by Schopper and Cote (1984) are not reviewed in this report. Rather the focus was on devices to obtain anthropometric measures such as those specified and standardized in NASA Reference Publication 1024 (Anthropology Research Project, 1978) and the Anthropometric Standardization Reference Manual (Lohman, Roche, & Martorell, 1988).

Early findings indicated that, while there is documentation describing "computerized" anthropometric measuring devices, most of these devices (Lueder, et al., 1994; Eklund & Corlett, 1984) have been used for research. Indeed the most recent, large-scale, comprehensive anthropometric survey (Gordon, et al., 1989) utilized manual measurement techniques. As far as the author could determine, there is only one "computerized" anthropometric measuring device in operational use for mass screening. That device, which is described later, is currently used by the Armed Forces in South Africa to determine the size of clothing to be issued to their personnel.

Table 1. Definitions of, and rationale for, anthropometric measures.

Dimension	Definition	Rationale
Stature (ST)	The vertical distance from the floor to a measuring probe placed firmly against the subject's scalp.	Needed to determine minimum overhead clearances.
Weight	Individual's weight as recorded on an electronic no-displacement transducer.	Needed for balance and center of gravity considerations.
Functional Arm Reach (FAR) (Thumb-Tip Reach)	The distance from the vertical plane to the point where the thumb and index finger are pressed together such that the greatest horizontal distance from the vertical plane is obtained while the subject is sitting erect, looking directly forward with his head, shoulders, back, and buttocks firmly positioned against the seat back.	Needed to determine location of flight and equipment controls (radios, navigation gear, circuit breakers, etc.).
Vertical Reach Downward	The distance between the acromial process on the right shoulder and the top of the right thumb when the arm is fully extended in downward direction.	Needed to determine location of side controls and collective.
Sitting Height (SH)	The distance between the seat surface and the top of the head when the subject is sitting erect, looking directly forward with his head, shoulders, back, and buttocks firmly positioned against the seat back.	Needed to determine minimum seat to canopy distance, maximum visual field, location of headrests, face curtains, and canopy piercers.
Eye height, Sitting	The distance between the seat surface and the eyes outer canthus when the subject is sitting erect, looking directly forward, with his head, shoulders, back, and buttocks firmly positioned against the seat back.	Needed to determine eye position of crew member, and to evaluate internal and external FOVs
Shoulder Height, Sitting (SHS);(Acromion Height, Sitting)	The distance from the seat surface to the top of the acromial process on the right shoulder when the subject is sitting erect with his back, shoulders, and buttocks firmly positioned against the seat back.	Needed to determine harness location, seat back length, and headrest position. SHS and FAR interact to determine control accessibility.
Shoulder Width (Bideltoid Breadth)	The distance across the shoulders between the greatest protrusion of the deltoid muscles.	Needed to determine seat back width and ejection clearances.
Hip Width, Sitting	The seated intertrochanteric distance.	Needed to determine seat pan width.
Buttock Knee Length	The distance from the back of the right buttock to the front of the right kneecap with the subject sitting erect.	Needed to determine the lower extensions of the instrument panel and ejection clearance for the knees.
Functional Leg Reach	The distance from the right buttock to a footrest, located 20 degrees below the top of the seat. The leg is fully extended with the buttock firmly positioned against the seat back. Pedal angle matches angle for full pedal deflection.	Needed to determine the location of brake and rudder pedals and the clearance necessary to prevent injury to lower extremities during ejection.
Knee Height, Sitting	The distance from the footrest surface to the musculature just above the knee.	Same as above.
Thigh Height, Sitting	The highest point on the upper surface of the thigh as measured from the seat surface.	Needed to determine clearance from yoke.
Upper Thigh Circumference	The circumference of the upper thigh is measured at largest circumference on the upper thigh.	Needed to determine regions of interference with lower ejection handle
Abdominal Depth Sitting	Measurement from the seatback to the maximum protrusion of the abdomen.	Needed to determine the limits of aft stick travel, before contact with crewmembers abdomen.

The author felt that measuring devices (e.g. laser scanning) used to design protective equipment (e.g., aviators helmets and oxygen masks), prosthetic devices, and clothing for a specific individual are currently not appropriate for gathering the anthropometric data during mass screening as desired by the Navy. Laser scanners can collect large amounts of data reliably and accurately. However, the operator must initially locate and mark the desired sites (usually with a dot made of felt-like material). Later, an operator intervenes as the required distances are "read," since extracting the data still requires operator intervention. In 1989, Pollock performed a preliminary examination of the possibility of using artificial intelligence (AI) techniques to automatically identify landmarks gathered by the optical surface scanning techniques. A good description of the complex issues associated with electronic imaging of the human body is provided in Vannier, Yates, and Whitestone (1992).

Daanen, Brunsman, and Taylor (1997) applied Integrate (a scan-data management tool developed by the Computerized Anthropometric Research and Design Laboratory) to data gathered on a Cyberware WB4 whole-body scanner. Since the purpose of their effort was to determine the absolute accuracy of the system, a calibration object, designed to mimic human body size and shape, was used. Skilled operators, performed the point picking task, obtained a absolute mean error of 2 mm. In measuring linear distances, approximately 90 percent of the point picking error was within =/- 4.12 mm. They estimate that additional software improvements could result in accuracies of =/- 0.5 mm. The authors believe that 88% of the error could be attributed to the resolution capability of the system. Thus well-trained operators, working under laboratory conditions, measuring a "cooperative" calibration object could obtain a reasonably high level of accuracy. The author of this report believes that such accuracies would not be obtained under field conditions using representative operators and live subjects.

In addition to these concerns, the anthropometric measures of interest, specified in Table 1, require that the subject assume two postures, standing and sitting. While a laser scanning system could be used to collect data on a standing individual, the task becomes more difficult when the individual is sitting, since the subject's body covers some of the reference points (e.g., seat back, & seat pan). Additionally, circumferential measurements cannot be gathered when an individual is positioned in a seat.

Since technology in the area of whole-body scanners is progressing rapidly and costs are falling, this area merits additional attention. However, because of the high cost, long subject preparation time, problems gathering circumferential data, and the requirement for skilled operator intervention during data analysis and reduction time, the author felt that laser scanning devices are not yet appropriate for gathering the data required by the Navy. Thus the author focused on approaches compatible with existing mass screening devices.

Measuring Devices Used for Mass Screening

With the exception of the device developed for use in South Africa, the devices described in this section are used to measure aircrew members.

In July 1965, Provost et al. developed an integrated measuring device (US PATENT # 3,196,551). This device measured the following anthropometric features: stature, thumbtip reach, sitting height, acromion height, buttock-knee length, buttock-heel length, and bideltoid diameter. Weight was measured by means of a beam scale. Originally, more than 50 of these devices were built and distributed to Naval Air Stations and Carriers. Ultimately, one of these devices was used at the Naval Aerospace Medical Institute (NAMI) to screen all candidates entering Naval Aviation. The device currently employed at NAMI is an updated version of the original device. Presently two Corpsmen operate the device, one positions the subject and reads the measurements, while the other manually records the measurement data.

Hendy, Anderson and Drumm (1984) developed an anthropometric "aid" for measuring the following anthropometric features: eye height (sitting), acromion height (sitting), functional reach, buttock-popliteal length, buttock-knee length, popliteal height, and knee height. The apparatus represented the seat and floor structure of the Australian CT4-A *Airtrainer*. The operator(s) of the device was required to position probes, visually verify the subject's position in the device (e.g., shoulders symmetrical and lightly touching the perspex (plexiglass) panel in the seat back), and manually record the measurements.

Gill (1986) developed a "body measurement rig" based on the design used in the Royal Air Force Institute of Aviation Medicine, Farnborough. The rig consists of:

> ...an end wall, a back wall and a floor mutually at right angles. A vertical track, parallel to the end wall, slides in horizontal tracks at the top and bottom of the rear wall. A carriage slides in the vertical track and carries a datum probe. The probe can be rotated through four 90-degree "stops" so that the datum is either parallel with the floor for measuring heights or parallel with the endwall for measuring widths. (p. 1)

The scales provide readings to the nearest millimeter of the distance of the probe from either the endwall or from the floor depending on the measurement being taken. The subject's dimensions were recorded manually on a data collection form.

Gill, like Hendy, Anderson and Drumm (1984), uses Perspex panels and mirrors to allow the operator to ascertain that the subject's shoulders, back, and buttocks are properly positioned against the seat back. Mirrors are also used to ascertain the position of the measuring tapes when circumference measures are taken. Mirrors are provided to allow the subject to look into the reflection of his/her eyes thus approximating the Frankfort Plane position. Markings and footprints are provided on the floor to facilitate the subjects self-positioning and to standardize the positioning of subjects.

Gill's jig requires the operator to mark, with a felt-tip pen, the following locations on the subject: waist, shoulder, acromion, cervicale, wrist, and knee. The rig allows the following measurements to be collected: elbow-fingertip length, elbow-wrist length, stature, waist height, crotch height, buttock-heel length, cervicale height, sitting height, mid-shoulder height, acromial height, elbow-rest height, bi-deltoid breadth, vertical functional reach, functional reach, chest depth, stomach depth, thigh clearance height, knee-height, and buttock-knee length.

In 1984, Moroney, Hughes and Spicuzza reported on an Automated Anthropometric Data Measurement System (AADMS), which collected data on the following dimensions: stature, weight, thumbtip reach, vertical reach downward, sitting height, acromion height sitting, bideltoid diameter, hip width, buttock-knee length, functional leg reach, and knee-height sitting. A patent was awarded in 1986 (Moroney, Bartholomew, Cagle, & Hughes). Figure 1 and Figure 2 provide an overview of the physical device. The components of the device are described in Appendix B; Figure 3 depicts the data flow within the system. Additional details on system operation are provided in Appendix C. Essentially, the individual to be measured is positioned in the device and when the position sensors confirm that he/she is properly positioned, the probes are lowered to the appropriate body landmarks. After the data have been recorded they are subjected to a statistical analysis to verify that:

1) the data are within acceptable ranges,
2) sufficient differences exist between related anthropometric measures (e.g., acromion height must be at least "x" inches less than sitting height), and
3) the recorded value is within the range predicted by multiple regression techniques.

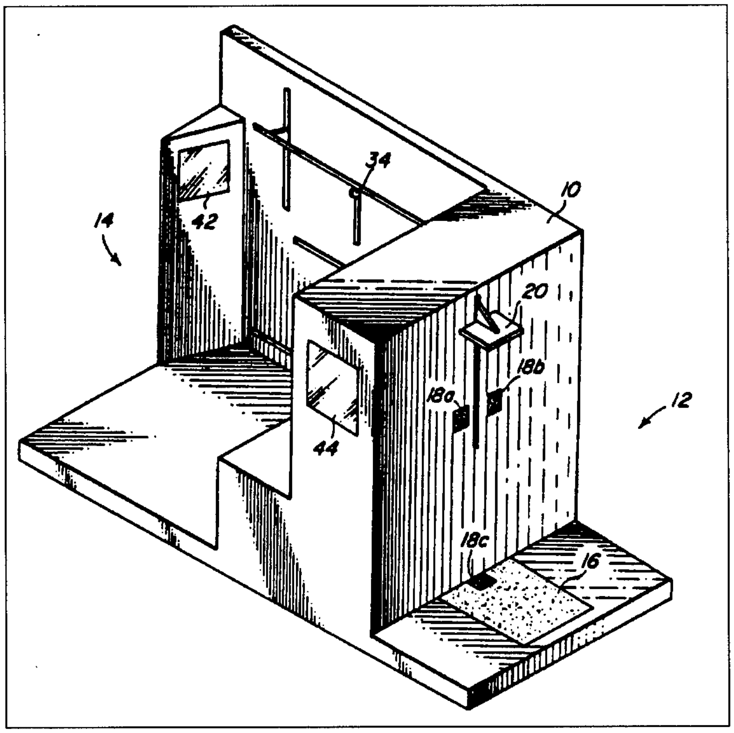

Figure 1. View of standing station proposed for the Automated Anthropometric Data Measurement Device. (Details are provided in Appendix B.)

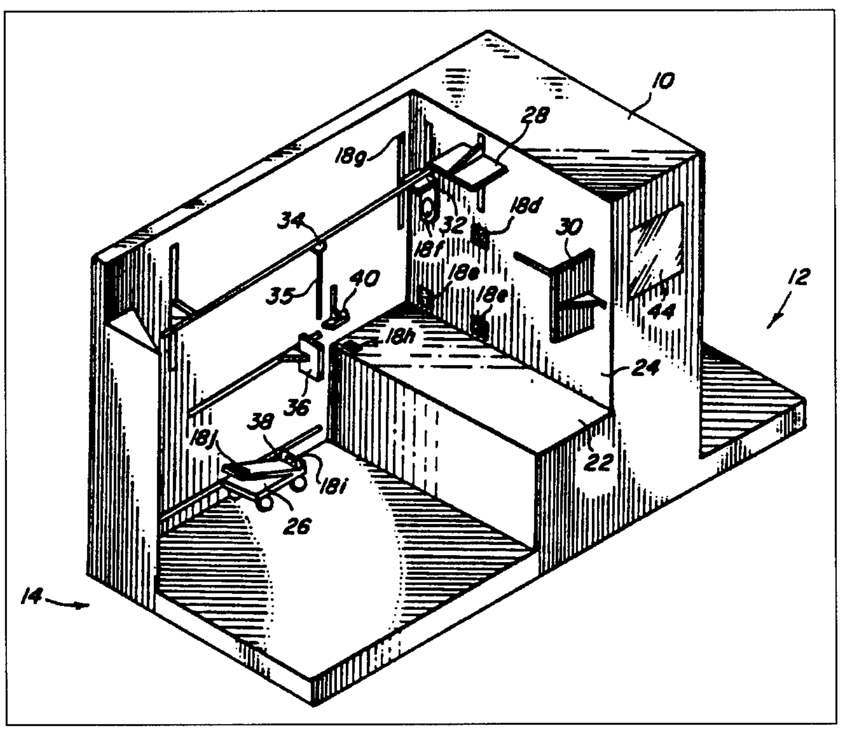

Figure 2. View of seated station proposed for the Automated Anthropometric Data Measurement Device. (Details are provided in Appendix B.)

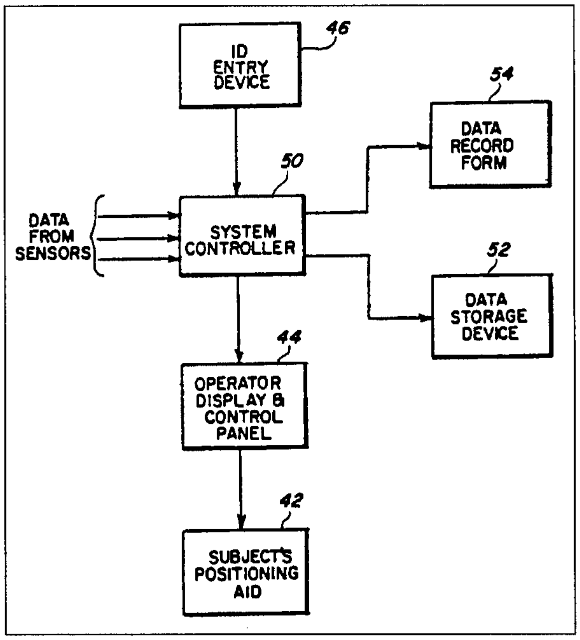

Figure 3. Flow of information proposed for the Automated Anthropometric Data Measurement Device. (Details are provided in Appendix B.)

Only after the data pass all three tests are they accepted into an individual's record. If discrepancies are noted, the operator is advised to re-measure the discrepant dimension, while the individual is still in AADMS.

A prototype of AADMS, which did not incorporate the data verification techniques described above, was built and subjected to an independent evaluation. Using a repeated-measures design, McConville, Case, and Clauser (1989) compared data collected on AADMS with data collected on two other versions of the Integrated Anthropometric Device used by the Navy to screen personnel for aircraft compatibility; techniques used in the 1964 anthropometric survey of Navy aviators; and, techniques used in the 1988 ANSUR survey (Gordon, et al., 1989). They reported that " ... in general, the AADMS is as good as or better than any of the other techniques and devices tested." However, they also noted that, as tested, "... AADMS cannot be operated without a highly trained operator and requires, in addition, a skilled technician for its maintenance." They provided a series of recommendations which would make AADMS more acceptable.

Ergotech, a firm in Pretoria, South Africa has developed an Anthropometric Measurement System (AMS) to "facilitate the efficient issuing of clothing items to defence force personnel." The AMS (Smith, 1996, Personal Communication) is very similar to the ADAMS device described earlier in that it uses electromechanical encoders, however AMS utilizes six measurement stations (see Figure 4) as opposed to the two stations used by ADAMS (see Figure 1 and Figure 2). Within a 5-minute period, AMS collects data on the following measurements: weight, stature, crotch height, inside arm length, foot width, and foot length; it also measures the following circumferences: head, chest, waist, hip, and palm. The data are entered into a 486DX 2-66 system either through the RS-232 communications link or by manual entry. The size of the clothing to be issued is then determined by the software. While the device described in Figure 4, currently collects data on 11 anthropometric features, the same technology could be modified to gather data on the anthropometric measures listed in Table 1. The accuracies reported for this device ranged from 2.5 mm (stature, crotch height) to 1 mm (foot length, circumference) to 0.5 mm (foot width). The Microsoft Windows compatible software uses a 486DX 2-66 PC with 8MB RAM, a 540MD hard drive.

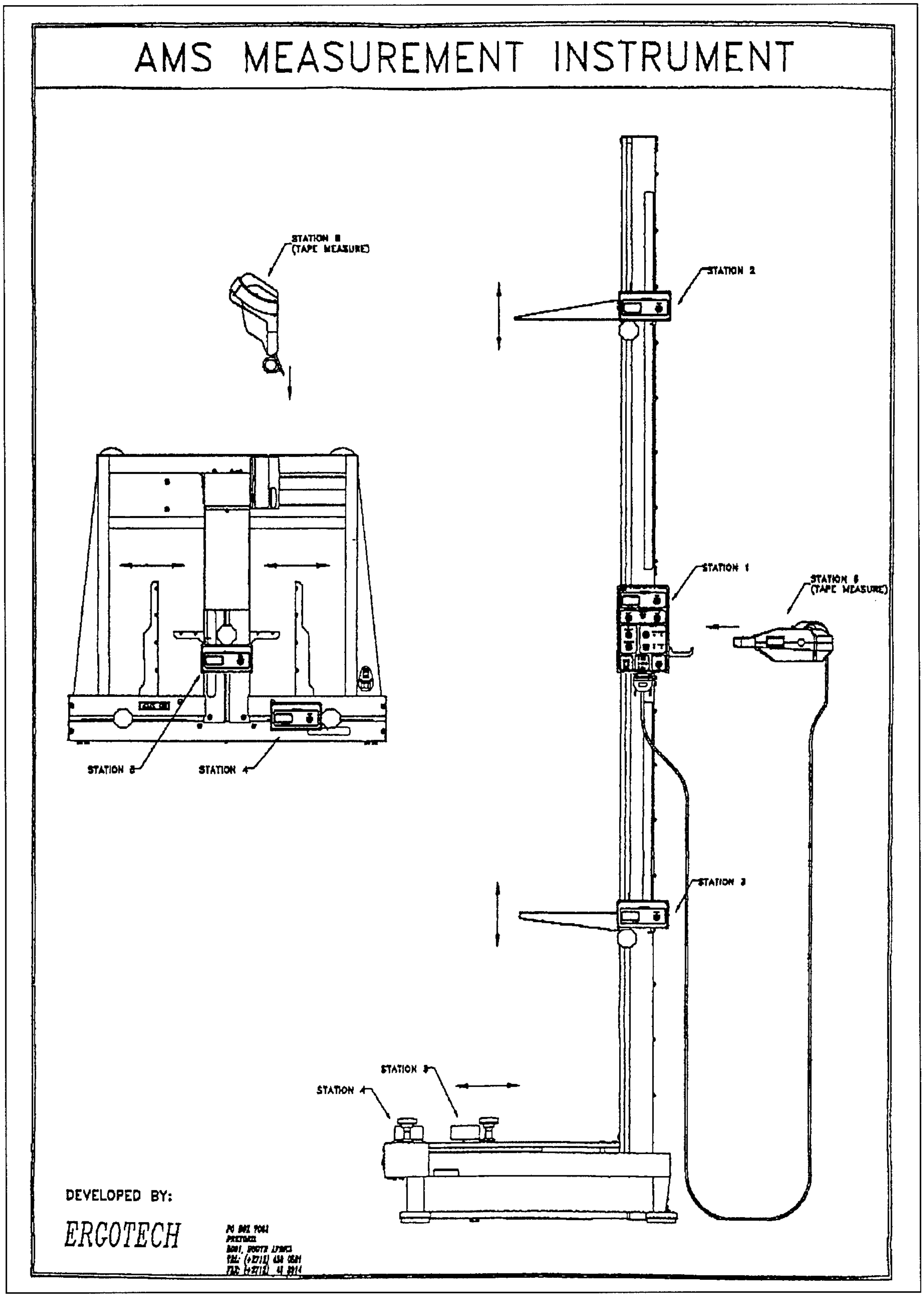

Figure 4. View of Anthropometric Measurement System developed by Ergotech. (Figure provided courtesy of Ergotech.)

Potentially Applicable Mensuration Technologies

Roebuck (1995) devotes a chapter of his monograph, *Anthropometric Methods: Designing to Fit the Human Body*, to measuring devices and procedures. This chapter expends the earlier work by Roebuck, Kroemer and Thompson (1975), *Engineering Anthropometry Methods*. The external measurement techniques described range from the traditional anthropometers, rigs and gauges, castings, electronic instruments (electromechanical/electromagnetic probes and sonic/light source digitizers), photographic techniques (grids, stereo photography, stereo video recording) to optical surface scanning methods (lasers, and phase measuring profilometry). Each of these types of systems have advantages and disadvantages in terms of accuracy, reliability, usability, and operator skill required. Photographic techniques require considerable hardware, operator intervention and attention to detail (see Woolford, 1985), while optical surface scanning methods are very expensive (usually in excess of $400,000 + additional software cost), and produce more data than are required for the basic measurement task. Therefore, the author will describe only electromechanical/ electromagnetic probes, acoustic/light source digitizers, and digitizing arms, which appear to be more cost-effective. They should be used in conjunction with an appropriately designed jig as part of an automated anthropometric measurement system, such as that described in the Moroney, Bartholomew, Kagle, and Hughes' patent (1986) to reliably achieve the desired accuracy.

An underlying assumption of this approach is the presence of a trained operator. Before data are entered into the system, this operator will ascertain the following: (a) the subject is properly positioned, and (b) that the measuring probes are properly positioned.

Some of the digitizing devices will require the operator to mark body locations, while the use of a jig, with probes that move to the body part, eliminates the need for body marking. However, use of the jig does not eliminate the requirement that the operator know what body part he or she is required to locate.

An excellent article (1996) by David Dean, of the Departments of Anatomy, Orthodontics, and Biomedical Engineering at Case Western Reserve University, lists tools designed to "assist in the analysis of macroscopic biological surfaces and volumes." The article is entitled *Three Dimensional Data Capture and Visualization*, and constitutes a chapter in *Advances in Morphometrics*. The sections of his chapter dealing with hand digitization, and rigid and servo-mechanism arms describe technologies which are particularly relevant to the development of an automated measurement system. The following sections are drawn from Dean's chapter, unless otherwise indicated. (Telephone numbers of some of the technology suppliers suggested by Dean and obtained from other sources are provided in Appendix D. Lists of digitizer manufacturers are available at http://fas.sfu.ca/cs/people/ResearchStaff/amulder/personal/vmi/HMTT.add.html and http://www.vrdepot.com.)

Digitization Devices

Modified anthropometers. A modified anthropometer (Figure 5 and Figure 6) is described by Snyder, Spencer, Owings, and Schneider (1975) in what was perhaps the first extensive use of automated anthropometry. Essentially, they modified a sliding caliper anthropometer by placing pressure transducers on the branches and mounting a ten-turn potentiometer at the fixed end of the anthropometer. A spring-loaded cable connected the potentiometer to the moving branch of the anthropometer. The potentiometer was calibrated to "read" the distance between the branches as a function of the number of turns taken on the potentiometer as the moving branch was positioned away from its origin (see Figure 5 and Figure 6). The pressure transducers at the ends of the branches were used to determine that a contact had been made by both branches.

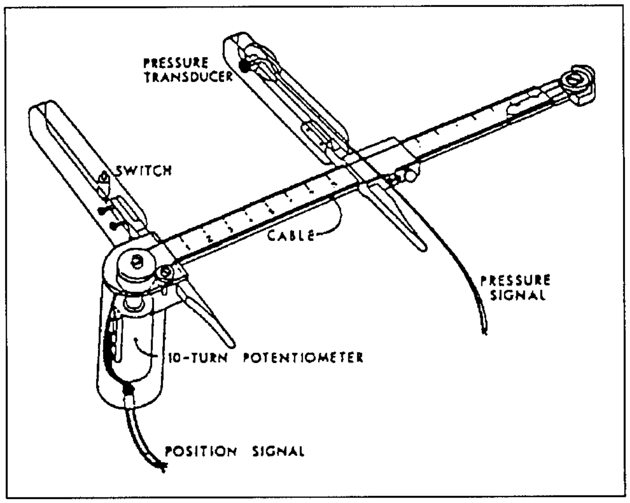

Figure 5. Drawing of modified sliding calipers with distance-sensing potentiometer. (Material reproduced from Snyder, R. G., Spencer, M. L., Owings, C. L., & Schneider, L. W., 1975.)

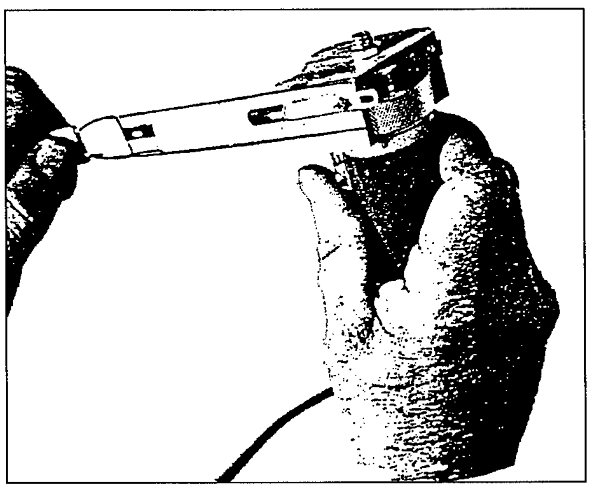

Figure 6. Photograph of modified sliding calipers with modified circumference-measuring device. (Material reproduced from Snyder, R. G., Spencer, M. L., Owings, C. L., & Schneider, L. W., 1975.)

The potentiometric device used in applications of this type have been improved and indeed are often replaced by optical encoders such as those described in Appendix B. Optical encoders not only offer higher resolution but are more reliable since the wiper which moves along the wire has been replaced by a light sensor which does not require physical contact.

Both the AADMS and the AMS devices could be classified as modified anthropometers (calipers) since, for the long dimensions, they essentially fix the body segment of interest between two points and measure the distance. Circumferences are measured the same way they would be with a standard measuring tape, except that the output is electronic rather than a numeric value read from the tape.

Digitizing probes. Digitizing probes are devices that emit a signal which pre-positioned receivers detect and locate in x, y, and z coordinates. These devices would be used while the individual is positioned in a pre-specified posture, in our case, either standing or seated. The probes are usually located on a hand-held stylus, which the operator positions at the point of interest (e.g., acromion or opthalion). Computer software is then used to define the distance from a pre-defined reference plane, such as the seat back or the floor.

Currently there are three types of digitizing probes: sonic, light, and electromagnetic; these probes are described in Table 2, Table 3, and Table 4, respectively.

Table 2. Acoustic technology.

Device	Freepoint	3D Mouse
Description	Uses 3 or more receivers to locate an acoustic (i.e. sparking) source	Uses 3 ultrasonic transmitters and 3 receivers to locate an source
Features/Costs	▪ Accuracy: nominally 0.1mm in 8 cubic foot area; 0.75mm at edge of range for Model3D-XL2 ▪ $7000 ▪ light weight	▪ Accuracy: nominally 0.1mm within 5-foot, 100 degree cone. ▪ $1599
Disadvantages	▪ Humidity & reflection artifacts exist, but software supplied may correct for them. ▪ Requires clear line of sight (i.e. no operator/subject LOS blockage)	▪ Humidity & reflection artifacts ▪ Requires clear line of sight (i.e. no operator or subject LOS blockage)
Recommendation /Comments	May be possible to extend probe, to maintain line of sight	May be possible to extend probe, to maintain line of sight
Sources	GTCO Corp (formerly: Scientific Accessories Corp)	Logitech

- The effectiveness of all these devices is in part a function of the distance between the emitter and the receiver, therefore appropriate caution should be used in comparing the devices.
- Cost estimates are approximate, and include software.

Table 3. Light technology.

Device	Pixsys 5000	Optotrak
Description	Uses 3 receivers to triangulate on the light source	Uses 3 CCD receivers to triangulate on IR light sources located in probe.
Features/Costs	▪ Accuracy: 1mm, within 2 cubic m. ▪ Light weight ▪ No humidity & reflection artifacts ▪ Cost: $28,000	▪ Accuracy: currently 0.1mm in x,y & 0.15mm in Z when stylus is within 2.25m of sensors. ▪ Cost: $60,000 ▪ Large FOV ▪ Light weight ▪ No humidity & reflection artifacts
Disadvantages	Requires clear line of sight (i.e. no operator or subject LOS blockage)	Requires clear line of sight (i.e. no operator or subject LOS blockage)
Recommendation /Comments	Receivers can be repositioned to increase area covered.	Motion measurement system exceeds requirements
Sources	Image Guided Technologies	Northern Digital Inc

- The effectiveness of all these devices is in part a function of the distance between the emitter and the receiver, therefore appropriate caution should be used in comparing the devices.
- Cost estimates are approximate, and include software.

Table 4. Electro-magnetic technology.

Device	3SPACE FASTRAC	3SPACE ISOTRAK II	Flock of Birds
Description	Uses receivers to detect magnetic fields emitted by the transmitter	Same	Same
Features/Costs	▪ Accuracy:0.08 mm for $6350; range of 10 feet ▪ Line-of sight not required ▪ Stylus	▪ Accuracy: 2.5mm for $3175; range of 5 feet. ▪ Line-of sight not required ▪ Stylus	▪ Accuracy: 0.08mm; range of 10 feet ▪ Cost $5090/ receiver & extended range transmitter; Additional receivers: $450 each ▪ Uses pulsed DC which reduces metallic distortion. ▪ receivers are tracked independently ▪ Line of sight not required
Disadvantages	Must correct for the presence of conducting material in area of interest, which is an expensive mapping process	Must correct for the presence of conducting material in area of interest, which is an expensive mapping process	No stylus available, but one could be manufactured
Recommendation /Comments			
Sources	Polhemus	Polhemus	Ascension Technology

- The effectiveness of all these devices is in part a function of the distance between the emitter and the receiver, therefore appropriate caution should be used in comparing the devices.
- Cost estimates are approximate, and include software.

The cost estimates provided are for the basic system and do not include additional costs associated with modifications to the data collection site, such as correcting for the presence of conducting materials which may distort the magnetic field.

Digitizing arms. The digitizing arms are counter-balanced, six degree-of-freedom, articulated arms with transducers in the joints. By monitoring the position of the joints, the x, y, and z coordinates of the probe at the end of the arm can be determined. Figure 7 is illustrative of an articulating arm system. Essentially, the operator moves the probe at the end of the arm to the point of interest. Since the system "knows" the point of origin, and the joints in the arms "sense" where they are being moved, and the distance between the joints is fixed, the position of the tip can be determined at all times.

Simpler versions of these arms have been used in laboratories. Das, Kozey and Tyson (1994) provide a good description of earlier laboratory devices. They also describe a prototype of a computerized, potentiometric measurement system which they developed. Their device uses four potentiometers attached through a series of pulleys and rods to a probe. As the probe is moved about, the KELVAR line, which turns the potentiometers, is payed in or out. Then the information on the length of the line payed out from the potentiometers is provided to the computer. There it

becomes the input for a linear algebra solution for the location of an unknown point. With this system, the mean algebraic errors in the x, y, and z axes were 4, -5, and - 2 mm. The estimated cost of their system's hardware was about $1600 (not including the A/D convertor and the computer).

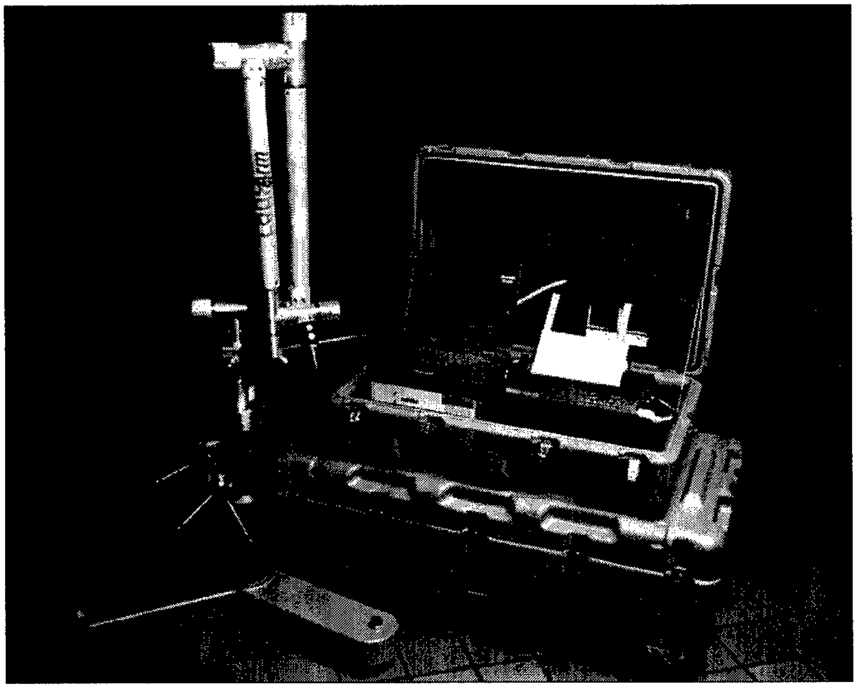

Figure 7. Digitizing arm. (Photograph courtesy of Faro Technologies.)

Table 5. Digitizing arm technology.

Device	**Space Arm**	**Faro Arm Bronze Series**	**Romer Model 2000**
Description	Six DOF, Uses four joints, the probe is located at the end of the last extension	Six DOF, Uses four joints, the probe is located at the end of the last extension	Six DOF, Uses four joints, the probe is located at the end of the last extension
Features/Costs	▪ Accuracy: 0.43mm, within a 6 ft range. ▪ Cost: $ 9,000	▪ Accuracy: ▪ 0.3mm within a 6 ft diameter. ▪ Cost: Basic Unit: $14,000. Turnkey systems start at $35,000	▪ Accuracy: 0.032mm within a 9.8' diameter. ▪ Uses Rotary joints for increased maneuverability ▪ Cost: $ 105,000
Disadvantages	▪ Probe must be repeatedly repositioned ▪ Measures must be collected one at a time.	▪ Probe must be repeatedly repositioned ▪ Measures must be collected one at a time.	▪ Probe must be repeatedly repositioned ▪ Measures must be collected one at a time.
Recommendation /Comments			
Sources	Faro Technologies	Faro Technologies	Romer Supratech Inc

▪ Cost estimates are approximate, and include software

Comparison of the Effectiveness of Digitizing Probes, Digitizing Arms, and Jigs

All of these digitizing technologies provide more than adequate accuracy (+/- 0.1 mm) and resolution (i.e. smallest increment that the device can measure) to meet the anthropometric measurement needs of the Navy. However, the repeatability of the devices cannot really be determined since the repeatability depends on the ability of the operator to reposition the device at exactly the same coordinates. The use of one probe to locate multiple body segments requires a serial process in which the operator moves the probe from landmark to landmark. This places a heavy attention-to-detail burden on the operator.

Furthermore, there are considerable differences in cost, capabilities, and limitations among the probes and arms. The acoustic (least expensive) and light sensors require an unobstructed line-of-sight between the transmitter and the receivers. Electro-magnetic technologies may require correction for the presence of conducting material. Digital arm technologies do not have these problems, but still require the operator to reposition the probe for each measurement. The author expects that system operators will encounter difficulty in *reliably* repositioning the probe when using real subjects and working at an operational tempo. Fortunately, the use of sliding devices in a jig (see the AMS and AADMS systems) only requires the operator to ascertain that the individual is positioned properly in the jig. Therefore the author recommends that a jig, with probes, be incorporated into any future design. Multiple probes, using any of the digitizing technologies described previously, could be used. However, given the requirement for a jig, potentiometric or optical encoders would be the least expensive digitizing technology.

While there may be some tradeoffs in selecting probes to measure body lengths, potentiometric or optical encoders are the technology of choice when circumference measures are required. Potentiometric or optical encoders do not have the "shadowing" problem that results when the subject's body part or the system operator's body interferes with the clear line-of-sight required by the digitizing probe.

Part IV: Straw-Man Requirements

Based on the research reviewed for this Review & Analysis, the following straw-man requirements are proposed:

1) Standing and sitting measures must be collected.

Measurements are needed in both the standing and sitting positions. A jig which ensures the correct positioning of the subject while requiring minimal operator intervention is needed. A device similar to that developed as AADMS or the AMS could meet the requirements. More than two data collection positions might be necessary for collecting sitting data. McConville, Case, and Clauser (1989) suggested that sitting upper and lower body measurements be taken separately.

2) Position sensors are needed.

It is essential that such a device be equipped with properly located and reliably positioned sensors. These sensors must be incorporated into a system which advises the operator that the individual is not properly positioned and serves as an interlock which prevents erroneous data from being recorded.

A display which assists the subject in positioning himself/herself correctly is desirable. Such a display could advise the subject to move a particular shoulder or buttock closer to the position sensor.

3) An accuracy of +/- 0.1 inch (2.5 mm) is adequate.

The accuracy requirement is a major determinant of cost and must be resolved before addressing technologies. It is well known that humans are tallest early in the morning and as the day progress, our stature gradually decreases due to the loading imposed on our spines. Hoe, Atha, and Murray-Leslie (1994) performed an interesting study which may help us to determine the required resolution. Using a repeated-measures design, they determined that with respect to a baseline, quiet walking lead to a mean stature loss of 1.82 mm (SE=0.49 mm; $p<0.01$), while steady running resulted in a mean loss of 4.32 mm (SE=0.83 mm, $p<0.01$). If individuals show a 2 mm decrement in stature as a result of merely walking, then a measurement system which provides accurate and reliable measurements within +/- 2.5 mm will meet the Navy's requirements.

4) Measurements should be taken within 3-5 minutes.

The measuring system chosen should be designed to collect the required data within the shortest period of time. Since the time available to measure the aviation candidates is limited to approximately three to five minutes per candidate, measurements must be completed within that window of opportunity.

5) Calibration checks are needed.

Irrespective of the technology selected, the device chosen must have built-in calibration checks. Subjects are often available for measurement only once and proper calibration is essential. The device should be calibrated before each data collection session.

6) Manual back-up is required.

Since the electronics portion of the equipment is subject to a total electrical failure, it would be desirable for such a measuring system to have a manual back-up. This could be achieved by the use of rulers and tape measures which are attached to or co-located with the probes. For standardization purposes, millimeters would be the preferred metric. However, until personnel performing the measurements become accustomed with reading metric scales, use of the inch units

would reduce errors. Finally, as recommended by McConville, Case, and Clauser (1989), the same units (either mm or tenth's of inches) should be provided by the manual back-up system and the automated measuring system.

7) Data checking is necessary.

A data checking strategy such as that described previously in the description of AADAMS and in Appendix C must be provided. The data checking must be performed while the subject is still available for re-measurement.

8) The system must be designed to reduce operator error.

Due to the turnover among corpsmen and the minimal training provided to them, a system which requires the use of correct procedures is essential. For example, the system should be designed such that measurements could not be taken until a calibration has been performed. Since this requirement would be problematic for maintainers of the system, a separate maintenance subroutine should be provided.

Software should be designed with checks such that demographic data must be entered correctly. For example, the entry for month of birth could not be less than 1 nor greater then 12.

Use of a magnetic card or a bar code, which contained the necessary demographic information for each person measured would reduce the probability of error considerably.

9) A maintenance schedule must be maintained.

A maintenance schedule must be established and Quality Assurance techniques applied.

10) Training is needed.

Due to the infrequent use of this device and personnel turnover, it would be appropriate to build a training mode into the PC system associated with the computer. This system could be supplemented by a video training tape.

11) The data collection system must provide data required by the Anthropometric Cockpit Assignment Program (Price, 1993).

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Appendix A

Requests for Information on Anthropometric Measuring Devices

Wanted: A device for measuring aviator body-size

We're searching for an existing device or package of tools that can be modified to systematically measure 14 specific anthropometric dimensions of aviators. In addition, this device should be able to readily download the obtained raw measures to a software package in order to compare them with existing cockpit data.

If you have any information that can lead to the acquisition of such a device please contact: Dr. William Moroney (during HFES Conf. @ Stouffer Hotel) Psychology Department/ University of Dayton, 300 College Park/ Dayton, OH 45469-1430/ 513-229-2767/ Fax:513-229-3900. or Dr. Floyd Glenn (during HFES Conf. @ Stouffer Hotel) CHI Systems, Inc. Gwynedd Office Park 716N. Bethlehem Pike, #300 Lower Gwynedd, PA 19002/215-542-1400/Fax:215-542-1412.

Figure 8. Announcement published at 1994 meeting of HFES

COMPUTERIZED ANTHROPOMETRIC MEASURING DEVICE

Information Sought:

I am looking for information on a measuring device or automated techniques, which could be used to develop an automated measuring device for screening purposes. The device would be used to measure personnel in both sitting and standing postures. It should reliably measure the following anthropometric features:

Standing: Stature, weight, thumbtip reach, bideltoid breadth, functional leg length

Sitting: Sitting height, eye height, acromion height, knee height, buttock knee length, thigh clearance, abdominal depth, Functional leg length, thigh circumference, hip breadth.

If you have information or thoughts on such a device, please contact me.

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Department of Psychology
University of Dayton
Dayton, OH 45469-1430
513-229-2767; FAX 513-229-3900
EMAIL: MORONEY@UDAVXB.OCA.UDAYTON.EDU

Figure 9. Announcement posted at 1994 and 1995 meetings of the Lucien Brouha Society for Work Physiology

Automated Anthropometric Measuring Device

Dear members of Biomch-L Discussion Forum,

I am looking for any information on computer based/automated measuring devices or computer based/automated measuring techniques, which could be used to gather anthropometric data for mass screening purposes. I am interested in measuring individuals in both sitting and standing postures. Ideally the device would quickly produce valid and reliably measurements of the following anthropometric features:

Standing: Stature, weight, thumbtip reach, bideltoid breadth

Sitting: Sitting height, Eye height, acromion height, knee height, buttock-knee length, functional leg reach, thigh clearance, abdominal depth, hip breadth.

Circumferences: Thigh

My current state of knowledge:
I am interested in gathering the type of data which would be gathered using conventional anthropometric instruments (rods with branches or blades). I am aware of the precision stadiometer described by Eklund & Corlett (1984). I do not believe that electronic imaging technology will meet my needs because it is still requires a skilled operator to provide landmarks and it is expensive. Furthermore, I am not interested in gathering body surface data. I have seen references to a "Linkoping Apparatus for the measurement of stature" and would like more information on that device and similar devices.

I will provide a listing of the replies which I receive to this request.

Thanks for any assistance you might provide.

William F. Moroney, PhD. CPE
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University of Dayton
Dayton, OH 45469-1430
USA

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EMAIL: MORONEY@SABER.UDAYTON.EDU

Figure 10. Announcement distributed on Internet to Biomch-L Discussion Forum

Appendix B

Copy of Patent on Automated Anthropometric Data Measurement System

(Patent begins on following page)

United States Patent [19]

Moroney et al.

[11] **Patent Number: 4,603,486**

[45] **Date of Patent: Aug. 5, 1986**

[54] **AUTOMATED ANTHROPOMETRIC DATA MEASUREMENT SYSTEM**

[75] Inventors: William F. Moroney, Chalfont, Pa.; James C. Bartholomew, Burke; Clifford M. Cagle, Reston, both of Va.; Robert E. Hughes, Albuquerque, N. Mex.

[73] Assignee: The United States of America as represented by the Secretary of the Navy, Washington, D.C.

[21] Appl. No.: 788,371

[22] Filed: Oct. 17, 1985

[51] Int. Cl.[4] A61B 5/10

[52] U.S. Cl. 33/512; 128/774; 128/781

[58] Field of Search .... 33/512, 511, 515, 169 R, 33/143 C; 128/774, 779, 781, 782

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4,134,213	1/1979	Kushmuk	33/169 R
4,425,713	1/1984	Rotella	33/512
4,492,236	1/1985	Pice	128/781

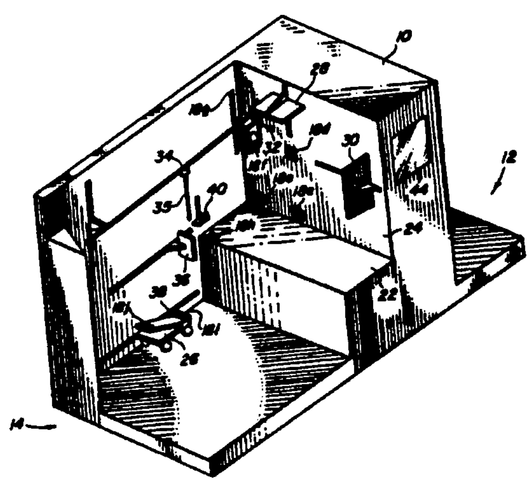
Primary Examiner—Willis Little

Attorney, Agent, or Firm—Robert F. Beers; Henry Hansen; James R. Burdett

[57] **ABSTRACT**

An automated anthropometric data measurement system includes a standing measuring assembly and a seated measuring assembly to determine pertinent anthropometric features of aviators being screened for assignment to particularly suitable aircraft. Both assemblies have a plurality of position sensors and measuring probes which are selectively placed by an operator upon the aviator, each measuring probe producing a digital data signal indicative of the particular feature measured when selective position sensors indicate body contact. The signals are then collected by a microcomputer which compares them to a predetermined population and outputs the compared data to magnetic storage media.

6 Claims, 3 Drawing Figures



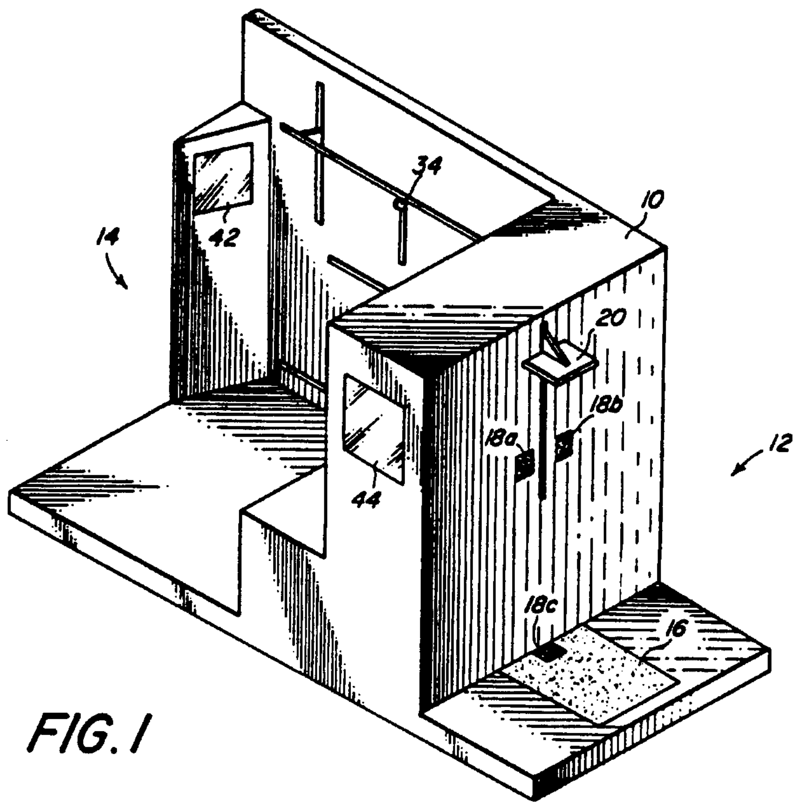

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FIG. 1

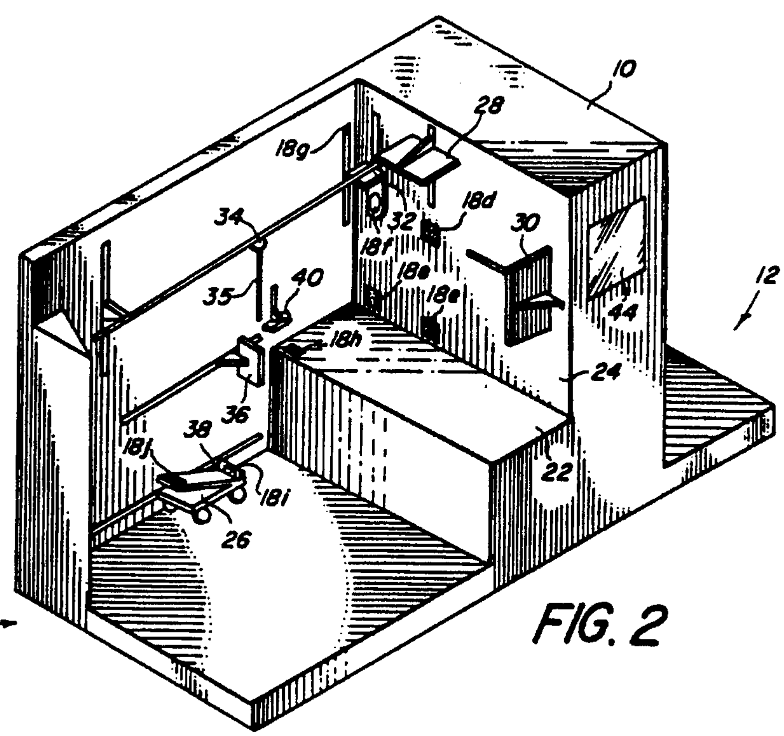
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FIG. 2

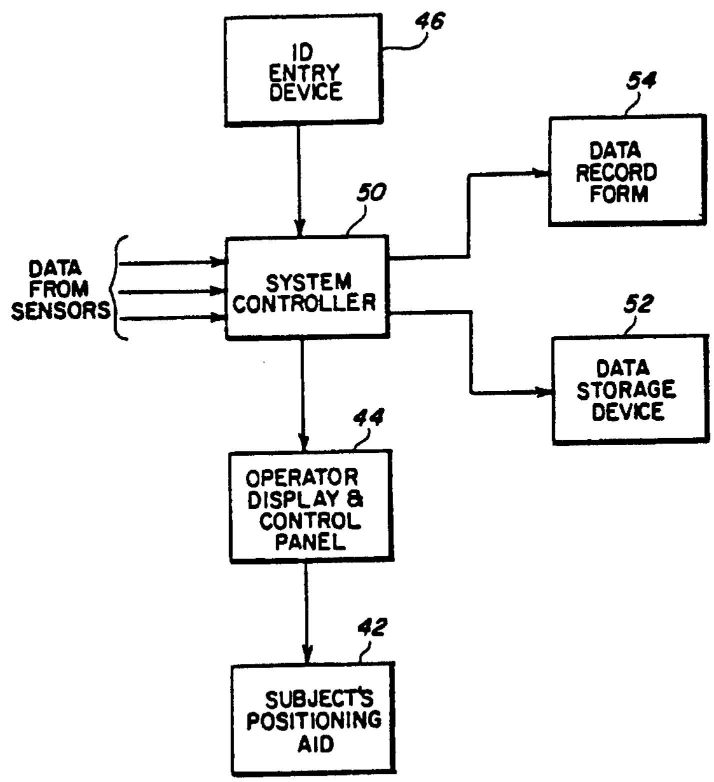
46
ID
ENTRY
DEVICE
54
DATA
RECORD
FORM
50
DATA
FROM
SENSORS
SYSTEM
CONTROLLER
52
DATA
STORAGE
DEVICE
44
OPERATOR
DISPLAY &
CONTROL
PANEL
42
SUBJECT'S
POSITIONING
AID

FIG. 3

TABLE I-continued

Dimension	Definition
	pressed together such that the greatest horizontal distance from the vertical plane is obtained while the subject is sitting erect, looking directly forward, with his head, shoulders, back, and buttocks firmly positioned against the seat back. The subject's feet should be resting flat on the floor.
Sitting Height (SH)	The distance between the seat surface and the top of the head when the subject is sitting erect, looking directly forward, with his head, shlioulders, back, and buttocks, firmly positioned against the seat back. The subject's feet should be resting flat on the floor.
Shoulder Height Sitting (SHS)	The distance from the seat surface to the top of the acromial process on the right shoulder when the subject is sitting erect with his back, shoulders, and buttocks firmly positioned against the seat back. The subject's feet should be resting flat on the floor.
Shoulder Width (SW)	The distance across the shoulders between the greatest protrusion of the deltoid müscles. It is measured with the subject sitting so that his shoulders, back, and buttocks are firmly positioned against the seat back; upper arms hanging at his sides and forearms extended forward. Subject's lungs should be fully expanded.
Buttock Knee Length (BKL)	The distance from the back of the right buttock to the front of the right kneecap with the subject sitting erect with his back, shoulders, and buttocks firmly positioned against the seat back. The subject's feet should be resting flat on the floor of the platform.
Functional Leg Reach (FLR)	The distance from the right buttock to the pivot point on a brake/rudder pedal assembly when the leg is extended as far as possible, while the subject is sitting erect with his back, shoulders, and buttocks firmly positioned against the seat back and his thigh positioned against the seat pan.
Knee Height, Sitting (KHS)	The distance from the footrest surface to the musculature just above the knee. It is measured with the subject sitting such that his shoulders, back, and the buttocks are firmly positioned against the seat back and his knee is bent to form a 90° angle.

The subject, following an operator's instructions, assumes an erect position upon the load cell 16 with his back flush to the upright position of the standing measuring assembly 12, touching sensors 18*a* and 18*b* and placing his heels together on the sensor 18*c*. While a simple microswitch may be used for the standing heel sensor 18*c*, the standing back sensors 18*a* and 18*b* are perfectly formed of a matrix of such switches. Once the subject is properly positioned, as determined by the simultaneous closure of the sensors 18*a*, 18*b*, and 18*c*, and as indicated to the operator on his Operator's Display and Control Panel 44, the operator lowers the ST probe 20 until it touches the top of the subject's head. In order to assist the operator in ensuring that the subject is properly positioned, the Operator's Display and Control Panel 44 includes a conceptual view of the subject with a number of red/green (go/no go) indicator lights equal to the number of position sensors. For example, by examining the view present when measurements such as the functional arm reach and functional leg reach are taken, the operator can detect unacceptable rotation of the hip or shoulder which would lead to an erroneously high value for these anthropometric dimensions. An optical or potentiometric encoding device (not shown) is attached to the ST probe 20 such that movement of the ST probe 20 causes a concomitant change in the value sensed by the encoding device. For

example, assuming that the encoding device is preset to a value of 84 inches, a ten-inch downward movement of the ST probe 20 to the top of the subject's head would indicate that the subject is 74 inches tall.

As shown more clearly in FIG. 2, the seated measuring assembly 14 is formed with a seat pan portion 22 and a seat back portion 24, and generally includes an adjustable foot pedal 26, and a plurality of position sensors 18*d* through 18*j* which are used in conjunction with a plurality of measuring probes 28, 30, 32, 34, 36, 38, and 40 to determine the remaining anthropometric features delineated in Table I as is discussed in further detail hereinbelow. Position sensors 18*d* through 18*j* may be configured similarly to the standing back sensors 18*a* and 18*b*, or may include a matrix which allows a small current to flow through the subject's back, ensuring continuity when his back is positioned properly, while the probes 28, 30, 32, 34, 36, 38, and 40 include encoding devices as used in the ST probe 20.

In order to determine the subject's sitting height (SH), the operator will instruct the subject to sit upon the seat pan portion 22 with his back and buttocks positioned to close the left shoulder blade sensor 18*d*, two buttock sensors 18*e*, and the right shoulder blades sensor 18*f*. A conceptual view of the seated subject with a number of indicator lights equal to the number of position sensors 18*d* through 18*j* is displayed on a Subject's Positioning Aid 42 which is situated to permit continuous observation by the subject during his evaluation. For example, a red/green indicator may be used for each position sensor 18*d* through 18*j* to indicate whether it is open or closed. When all four sensors 18*d*, 18*e*, and 18*f* are simultaneously closed, the operator lowers the SH measuring probe 28 to the top of the subject's head thus measuring his sitting height (SH) in a manner analogous to that described for the stature (ST) measurement.

The subject's shoulder width (SW), shoulder height sitting (SHS), and buttock-knee length (BKL) are similarly determined. For shoulder width (SW), the left shoulder blade sensor 18*d*, buttock sensors 18*e*, right shoulder blade sensor 18*f*, and the right shoulder wall sensor 18*g* must be closed before the operator can position the SW measuring probe 30 against the subject's left shoulder. The same sensors 18*d*, 18*e*, 18*f*, and 18*g* must be closed prior to the operator's lowering of the SHS measuring probe 32 to the top of the subject's right shoulder in order to determine his shoulder height sitting (SHS). Likewise, in order to determine the subject's buttock-knee length (BKL), the seat back sensor 18*d*, buttock sensors 18*e*, and the thigh sensor 18*h* must be closed before the operator positions the BKL measuring probe 36 against the subject's right knee.

For a determination of the subject's functional arm reach (FAR), the left shoulder blade sensor 18*d*, buttock sensors 18*e*, and right shoulder blade sensor 18*f* must first be closed. The operator then instructs the subject to extend his right arm fully, keeping sensors 18*d*, 18*e*, and 18*f* closed, such that the juncture of his thumb and index finger touches a vertical extension 35 of the FAR Measuring probe 34. In order to determine the subject's functional leg reach (FLR), the left shoulder blades sensor 18*d*, buttock sensors 18*e*, thigh sensor 18*f*, and the heel and toe sensors 18*i* and 18*j* located on the pedal assembly 26 must be closed while the subject extends his right leg as far as he can while keeping his foot on the pedal assembly 26 which includes the FLR

measuring probe 38. Likewise, the left shoulder blade sensor 18d, buttock sensors 18e, and thigh sensor 18f must be closed while the operator positions the KHS measuring probe 40 to the top of the subject's right knee in order to determine the subject's knee height sitting. A summary of the position sensor setting required for each anthropometric characteristic is presented in Table II.

TABLE II

Position Sensors	Position Sensor Number	ANTHROPOMETRIC FEATURE Stature	Sitting Height	Shoulder Width	Shoulder Height Sitting	Functional Arm Reach	Buttock-Knee Length	Functional Leg Reach	Knee Height Sitting
Standing Heel	18c	X							
Standing Back	18a, 18b	X							
Left Shoulder Blade	18d		X	X	X	X	X	X	X
Buttocks	18e		X	X	X	X	X	X	X
Right Shoulder Blade	18f		X	X	X	X			
Right Shoulder (Wall)	18g			X	X				
Thigh	18h						X	X	X
Heel (Pedal)	18i							X	
Toe	18j							X	

Having explained in some detail the structural features of the present invention, its operation will now be summarized with reference to FIG. 3. The operator first enters the subject's identification into the AADMS 10 at an ID entry device 46, either manually or through the insertion of a pass card into a conventional card reader. An indication of the subject's identification is subsequently displayed via a conventional microcomputer or system controller 50 on an ID and Measurement Readout 48 located on the Operator's Display and Control Panel 44.

The subject then assumes the required position, following operator instructions, in either the standing measuring assembly 12 or the seated measuring assembly 14 and ensures that the applicable position sensors are closed by observing the Subject's Positioning Aid 42. When the subject is positioned correctly and the appropriate measuring probe is in place, data are allowed to flow to the system controller 50 from the respective encoding device attached to each probe. If the required position sensors have not been closed, the necessary corrective action (i.e., a red light indicating which sensors needs to be closed) is displayed on the Operator's Display and Control Panel 44. Anthropometric data will be recorded only when the subject is positioned correctly.

After the system controller 50 receives the data from the particular measuring probe and displays that data on the Operator's Display and Control Panel 44, the controller 50 executes a number of data reasonability checks, such as determining whether the data are in range of known anthropometric valves and whether certain related measurements such as sitting height and shoulder height sitting have sufficient differences between them. If a discrepancy is noted, it will also be displayed on the Operator's Display and Control Panel 44.

For example, in order to verify that the data are within acceptable ranges, a series of checking routines within the system controller 50 prevent values such as sitting heights greater than 44 inches or less than 30 inches from being entered into the AADMS 10. These minimum-maximum values are based on data associated with similar male and female populations. On the other hand, in order to verify that sufficient differences exist between various anthropometric measurements, another series of routines within the system controller 50 will, for example, ensure that the sitting height minus the shoulder height sitting must be at least 9.9 inches and connot exceed 14.3 inches. These routines are, again, based on similar data from the general population.

When data from each of the anthropometric features listed in Table I have successfully been collected, such observed data is compared in the system controller 50 to a prediction model stored therein. If the differences between the observed and the predicted values do not exceed a set of predetermined limits, then the data are accepted and stored on a data storage device 52 such as a magnetic disk or recorded on a standardized anthropometric data record form 54. For example, by inserting the required values into prestored, conventional regression equations, predicted anthropometric dimensions can be obtained. If the predicted stature were assumed to be equal to the sitting height plus the functional leg reach plus a predetermined constant, and the measured value fell within a predetermined range around the predicted value, then the system controller 50 would consider it valid. While the AADMS 10 is designed to work normally in an automatic mode, a manual mode is provided as a back-up in the preferred embodiment of the present invention. In the manual mode the data are copied manually onto an appropriate record form.

Some of the many advantages of the invention should now be readily apparent. For example, a novel system has been provided which is capable of quickly and reliably determining selected anthropometric features for use in screening aviators for assignment to the respective aircraft. Moreover, the system provided is adaptable to magnetic storage media.

Obviously many modifications and variations of the present invention are possible in light of the above teachings. It is therefore to be understood that within

the scope of the appended claims, the invention may be practiced otherwise than as specifically described.

What is claimed is:

1. An anthropometric data measurement system for screening an aviator for subsequent assignment to a particularly suitable aircraft, comprising in combination:

a first measuring assembly for determining the aviator's stature;

a second measuring assembly including a seat, having a seat pan portion and a seat back portion, and a pedal assembly for determining the aviator's sitting height, shoulder height sitting, shoulder width, functional arm reach, buttock-knee length, functional leg reach, and knee height sitting;

a display and control panel for assisting an operator in the correct placement of the aviator and selecting the respective anthropometric feature to be measured;

a positioning aid observable by the aviator for assisting him in maintaining a position required for the respective anthropometric feature to be measured;

system controller means for collecting the measurements determined by said first and second measuring assemblies, comparing the collected measurements to a predetermined set of upper and lower limits, performing data reasonability checks and outputting said collected measurements when they fall within said predetermined set of upper and lower limits; and

archival means for storing the measurements output from said system controller means.

2. A system according to claim 1, wherein said first measuring assembly comprises:

a first base member;

a back member mounted on and extending vertically upward from said base member;

a stature measuring probe slidably mounted within and disposable vertically along an axis bisecting said back member for producing a digital data signal indicative of the aviator's stature;

a pair of standing shoulder position sensors, each including a matrix of microswitches mounted on said back member;

a standing heel position sensor including a microswitch mounted on said base member at the point at which it intersects the back member;

wherein said digital data signal indicative of the aviator's stature is output from said stature measuring probe to said system controller means when said pair of shoulder position sensors and said standing heel position sensor are simultaneously closed.

3. A system according to claim 2, wherein said first measuring assembly further comprises a load cell mounted within said base member to determine the aviator's weight and produce a digital data signal indicative thereof.

4. A system according to claim 1, wherein said second measuring assembly comprises:

a second base member upon which said seat is mounted;

a side member mounted on and extending vertically upward from said second base member, said side member abutting the right side of said seat;

a sitting height measuring probe slidably mounted within and disposable vertically along said seat back portion for producing a digital data signal indicative of the aviator's sitting height;

a shoulder width measuring probe slidably mounted within and disposable horizontally along said seat back portion for producing a digital data signal indicative of the aviator's shoulder width;

a shoulder height sitting measuring probe slidably mounted within and disposable vertically along said seat back portion for producing a digital data signal indicative of the aviator's shoulder height sitting;

a functional arm reach measuring probe slidably mounted and disposable horizontal along said side member for producing a digital data signal indicative of the aviator's functional arm reach;

a buttock knee length measuring probe slidably mounted within and disposable horizontally along said side member for producing a digital data signal indicative of the aviator's buttock knee length;

a functional leg reach measuring probe attached to said pedal assembly for producing a digital data signal indicative of the aviator's functional leg reach;

a knee height sitting measuring probe slidably mounted within and disposable vertically along said side member for producing a digital data signal indicative of the aviator's knee height sitting;

a pair of buttocks position sensors, each including a matrix of microswitches mounted on said seat back portion;

a left shoulder blade position sensor including a matrix of microswitches mounted on said seat back portion at a point approximately where the seated aviator's left shoulder blade would touch;

a right shoulder blade position sensor including a matrix of microswitches mounted on said shoulder height sitting measuring probe;

wherein said digital data signals indicative of the aviator's sitting height and functional arm reach are output from their respective measuring probe to said system controller means when said pair of buttocks position sensors, and said left and right shoulder blade position sensors are simultaneously closed;

a right shoulder wall position sensor including a matrix of microswitches mounted on said side member at a point approximately where the seated aviator's right shoulder would touch;

wherein said digital data signals indicative of the aviator's shoulder width and shoulder height sitting are output from their respective measuring probe to said system controller means when said pair of buttocks position sensors, said left and right shoulder blade position sensors, and said right shoulder wall position sensor are simultaneously closed;

a thigh position sensor including a matrix of microswitches mounted on said seat pan portion at a point approximately where the seated aviator's right thigh would touch;

wherein said digital data signals indicative of the aviator's buttock knee length and knee height sitting are output from their respective measuring probe to said system controller means when said pair of buttocks position sensors, said left shoulder blade position sensor, and said thigh positon sensor are simultaneously closed;

a pair of pedal position sensors, one mounted at the heel and one at the toe of said pedal assembly;

wherein said digital data signal indicative of the aviator's functional leg reach is output from said functional leg reach measuring probe to said system controller means when said pair of buttocks position sensors, said left shoulder blade position sensor, said thigh position sensor, and said pair of pedal positon sensors are simultaneously closed.

5. A system according to claim 1, wherein said system controller means further comprises:

a display and control panel situate between said first and second measuring asemblies for selecting the anthropometric feature to be measured, indicating the state of each position sensor, and displaying the numeric value of the collected measurement.

6. A system according to claim 1, wherein said archival means comprises a magnetic storage medium.

* * * * *

Appendix C

Development of an Automated Anthropometric Data Measurement System

(Paper begins on following page)

DEVELOPMENT OF AN AUTOMATED ANTHROPOMETRIC DATA MEASUREMENT SYSTEM (AADMS)

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ABSTRACT

Due to the limited space available in modern cockpits and crewstations, certain critical anthropometric features of an aviator must be measured properly. Unreasonable and erroneous anthropometric values are sometimes recorded because of measuring and operator errors. The purpose of the Automated Anthropometric Data Measurement System (AADMS - pronounced ADAMS) is to reliably and accurately measure anthropometric features in a timely and efficient manner and to eliminate the source of many of these errors. AADMS utilizes a microcomputer interfaced to a variety of position sensors and transducers to gather and internally verify data on 11 anthropometric parameters.

INTRODUCTION

Due to the limited space and complex operability requirements associated with aircraft cockpits, it is essential that the critical anthropometric features of potential aircrewmen be measured properly. However, due to measurement and recording errors, incorrect anthropometric values are sometimes recorded. These errors can result in assigning aircrew to aircraft with which they are not compatible or conversely restrict individuals from aircraft that they could in reality operate without difficulty. Either alternative is costly and dangerous. Erroneous anthropometric data can confound the analysis of aircraft accidents and resulting aircrew injury and can mislead designers of future aircraft cockpits and personal equipment.

Traditionally, anthropometers and calipers have been used to measure linear and circumferential dimensions of the human body. These devices require skilled operators and are time-consuming. Therefore, the Automated Anthropometric Data Measurement System (AADMS) has been developed.

Overall System Description

The system is designed to measure each of the dimensions listed in table I. While the rationale provided for the inclusion of these dimensions emphasizes considerations related to the design of cockpits, justifications could also be provided for considering these dimensions in the design of industrial workspaces and vehicles. In addition, other measurements, such as curvatures, circumference, depths, and arcs, could be taken by using this approach. The Automated Anthropometric Measuring System consists of three functional units:

1. Operator's Control and Display Panel - An electronic equipment rack which houses a keyboard, cathode ray tube (CRT), disk drives, microcomputer, printer, and transducer interfaces.
2. Standing Measuring Assembly - Stature, weight, and bideltoid (shoulder) width are measured at the right side of the assembly shown in figure 1.
3. Seated Measuring Assembly - Sitting height, shoulder (acromial) height, functional arm reach, vertical reach downward, hip (intertrochanteric) width, knee height, buttock knee length, and functional leg length are measured at the left side of the assembly shown in figure 1.

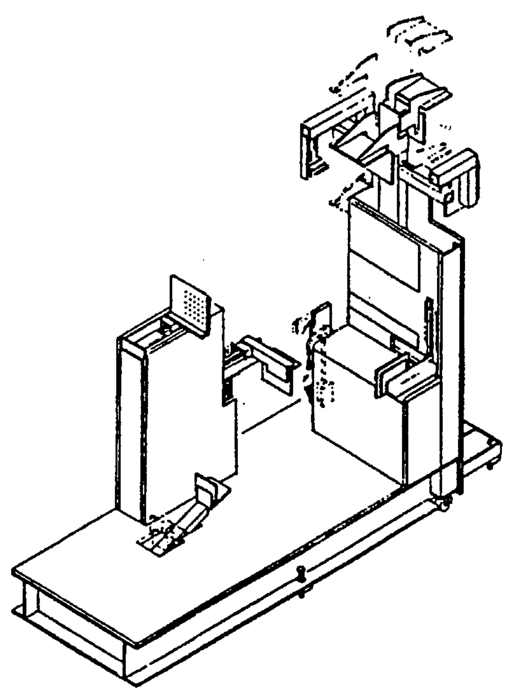

Figure 1 Seated and Standing Measuring Assembly

Table I Definitions of and Rationale for Anthropometric Features Recorded by AADMS

Dimension	Definition	Rationale
Stature (ST)	The vertical distance from the floor to a measuring probe placed firmly against the subject's scalp.	Needed to determine minimum overhead clearances.
Functional Arm Reach (FAR)	The distance from the vertical plane to the point where the thumb and index finger are pressed together such that the greatest horizontal distance from the vertical plane is obtained while the subject is sitting erect, looking directly forward with his head, shoulders, back, and buttocks firmly positioned against the seat back.	Needed to determine location of flight and equipment controls (radios, navigation gear, circuit breakers, etc.).
Vertical Reach Downward (VRD)	The distance between the acromial process on the right shoulder and the top of the right thumb when the arm is fully extended in a downward direction.	Needed to determine location of side controls and collective.
Sitting Height (SH)	The distance between the seat surface and the top of the head when the subject is sitting erect, looking directly forward with his head, shoulders, back, and buttocks firmly positioned against the seat back.	Needed to determine minimum seat to canopy distance, maximum visual field, location of headrests, face curtains, and canopy piercers.
Shoulder Height Sitting (SHS)	The distance from the seat surface to the top of the acromial process on the right shoulder when the subject is sitting erect with his back, shoulders, and buttocks firmly positioned against the seat back.	Needed to determine harness location, seat back length, and headrest position. SHS and FAR interact to determine control accessibility.
Shoulder Width (SW)	The distance across the shoulders between the greatest protrusion of the deltoid muscles.	Needed to determine seat back width and ejection clearances.
Hip Width, Sitting (HWS)	The seated intertrochanteric distance.	Needed to determine seat pan width.
Buttock Knee Length (BKL)	The distance from the back of the right buttock to the front of the right kneecap with the subject sitting erect.	Needed to determine the lower extensions of the instrument panel and ejection clearance for the knees.
Functional Leg Reach (FLR)	The distance from the right buttock to a footrest, located 20 degrees below the top of the seat, with the leg fully extended and the buttock firmly positioned against the seat back.	Needed to determine the location of brake and rudder pedals and the clearance necessary to prevent injury to lower extremities during ejection.
Knee Height, Sitting	The distance from the footrest surface to the musculature just above the knee.	Same as above.
Weight	Individual's weight as recorded on an electronic nondisplacement transducer.	Needed for balance and center of gravity considerations.

Operating Procedures

Briefly, AADMS operates in the following fashion:

a. The operator enters the subject's identification into the microcomputer.

b. The subject, following operator instructions, assumes the required position in either the Standing Measuring Assembly or the Seated Measuring Assembly.

c. The Position Sensors ensure that the individual satisfies certain critical positioning functions (for example, heels against the back wall for stature, buttocks and back flush for seated measurements, etc.).

d. The appropriate probes are then positioned on the desired landmarks (e.g., sitting height probe is lowered to the top of the head, buttock-knee length/knee height sitting probe is moved to the tibial and patellar surfaces).

e. Assuming that the individual is positioned correctly (i.e., meets criteria contained in the microcomputer), data are allowed to flow to the microcomputer from transducers attached to each probe. If the appropriate position sensors have not been closed, the required corrective action is displayed on the operator's display. Anthropometric data will be recorded only when the subject is positioned correctly.

f. After the microcomputer receives the data, it executes a number of "data reasonability checks." If a discrepancy is noted, that problem area is displayed on the Operator's Display and Control Panel and the corrective action to be taken is indicated.

g. Finally, after all the data have been collected, the observed data are compared with the results obtained from a prediction model stored in the microcomputer. If the differences between the observed and the predicted values do not exceed specified limits, the data are accepted and stored on the Data Storage Device (disk) and/or an Anthropometric Data Record Form is printed.

Unique Features

AADMS incorporates:

1. Position Sensors to eliminate the most common sources of errors related to incorrect positioning.

2. Transducers to quantify the anthropometric variables.

3. A means for verifying reasonability of the data.

Each of these features is discussed below:

Position Sensors. Position Sensors are installed in the Standing Measuring Assembly (to verify heel position) and in the Seated Measuring Assembly (to verify shoulders and buttocks placement). While the heel positioning sensor is essentially a microswitch, the shoulders and buttocks placement sensors require a matrix of switches. The shoulder position matrix consists of switches (each 0.75 inch on an edge) contained within a 10 inch by 17 inch array. The buttock position matrix consists of switches (same size as above) within a 4 inch by 17 inch array. When the individual is initially seated, the operator can view an x,y plot on the CRT indicating which switches are closed. If the plot appears reasonable to the operator and is similar to a generic image of the expected plot stored within the microcomputer, the baseline image is accepted. By comparing this image with the image present when measurements such as functional arm reach and buttock leg reach are taken, it is possible, by use of a series of rules, to detect unacceptable rotation of the hip or shoulder which would lead to an erroneously high value for these anthropometric dimensions.

Transducers. While load cells are used to determine weight, a variety of potentiometric or optical encoding devices is used to record the remaining anthropometric data. An encoding device is attached to each probe (e.g., the headplate, figure 1, used to measure sitting height) and, as the probe is moved toward the appropriate landmark, a corresponding change occurs in the encoding device. For example, as the sitting height probe located 44 inches above the seat is moved toward the top of the subject's head, the transducers provide an input to the computer which subtracts the input from the starting distance. Other transducers work in an analogous fashion.

Verification of Data Reasonability. The reasonability of the data is verified by the following serial checks:

1. Verifying that the data are within acceptable ranges.

   Checking routines within the microcomputer prevent values such as sitting heights greater than 44 inches or less than 30 inches from being entered into the system. These minimum-maximum values are based on data associated with similar male and female populations.

2. Verifying that sufficient differences exist between anthropometric measurements.

   Routines within the microcomputer verify that sufficient differences exist between appropriate anthropometric measurements. For example, sitting height minus shoulder height (sitting) must be at least 9.9 inches and cannot exceed 14.3 inches.

3. Prediction based on multiple regression.

   By inserting the required values into prestored regression equations, predicted anthropometric dimensions can be obtained. For example:

   Predicted Stature = W1 (Sitting Height) + W2 (Functional Leg Reach) + K. If the measured value falls within a prespecified bound around the predicted value, then it is considered valid.

Evaluation of AADMS

AADMS will be thoroughly evaluated at the Naval Aerospace Medical Research Laboratory during late 1984 and 1985. In addition to obtaining reliability data, improved criteria for defining correct positioning and improved data verification techniques will be developed.

Appendix D

Sources of Digitizing Devices

Acoustic Technology

GTCO Corporation
7125 Riverwood Drive
Columbia, MD 21046
410.381.6688

LOGITECH Inc
6505 Kaiser Drive
Fremont, CA 94555
Phone: 510.795.8500

Digitizing Arm Technology

Faro Technologies, Inc
125 Technology Park
Lake Mary, Fl 32746
Phone: 800.736.0234

Romer Supratech Inc
2331 Monroe Blvd
Dearborn, MI 48124
Phone: 513.642.1237

Electo-Magnetic Technology

Ascension Technology Corp
P.O. Box 527
Burlington, VT 05402
Phone:802.860.6440
Email: ascension@world.std.com
WWW.ascension-tech.com

Polhemus
PO Box 560
1 Hercules Drive
Colchester, VT 05446-0560
Phone:802.655.3159

Electro-Mechanical Technology

Ergotech Ergonomics Consultants
PO Box 7063
Pretoria. 0001
South Africa
Phone: + 27 12 012. 428.0572
Email: jaco@dendex.denel.co.za

Light Technology

Image Guided Technologies, Inc
5710-B Flatiron Parkwqy
Boulder, Co 80301
Phone 303.447.0248

Northern Digital Inc
403 Albert Street
Waterloo, Ontario
Canada NL2 3V2
Phone:519.884.5142 or 800.265.2741

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CSERIAC's primary objective is to acquire, analyze, and disseminate timely information on human factors and ergonomics. On a cost-recovery basis, CSERIAC will:

- Distribute human factors and ergonomics technologies and publications
- Perform customized bibliographic searches and reviews
- Prepare state-of-the-art reports and critical reviews
- Conduct specialized analyses and evaluations
- Organize and conduct workshops and conferences

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